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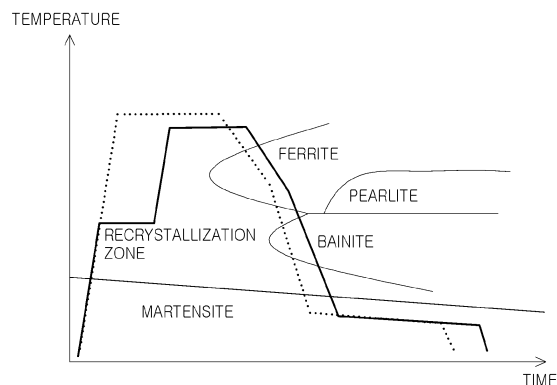
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(54) **HIGH-STRENGTH AND THICK STEEL SHEET HAVING EXCELLENT HOLE EXPANDABILITY AND DUCTILITY, AND MANUFACTURING METHOD THEREFOR**

(57) The present invention relates to steel suitable as a material for automobiles and, particularly, to a high-strength and thick steel sheet having excellent hole expandability and ductility, and a manufacturing method therefor.

[FIG. 1]



Description

Technical Field

- 5 **[0001]** The present disclosure relates to a steel suitable for an automotive material, and particularly, to a high-strength thick steel sheet having excellent hole expandability and ductility, and a method for manufacturing the same.

Background Art

- 10 **[0002]** In recent years, the use of a high-strength steel has been demanded for improving fuel efficiency or durability due to various environmental regulations related to CO₂ emissions and energy use regulations.

[0003] In particular, as regulations for impact stability of automobiles have expanded, a high-strength steel having excellent strength is being adopted as a material of structural members such as a member, seat rail, and a pillar for improving impact resistance of a car body.

- 15 **[0004]** Since automotive parts have a complicated shape depending on stability and design thereof, and are manufactured by forming with a press mold, the automotive parts require to have a high level of formability together with high strength.

- [0005]** As the strength of steel is high, the steel is favorable to energy absorption, but generally, when the strength is increased, elongation is decreased to reduce forming processability. Besides, when yield strength is excessively high, introduction of a material into a mold during forming is decreased to deteriorate formability and increase manufacturing costs.

- [0006]** In addition, as automotive parts have a plurality of forming areas in which a hole is processed and then expands, hole expandability is required for smooth forming, but high-strength steel sheet has low hole expandability (HER) to cause defects such as cracks during forming. As such, when hole expandability is poor, cracks may occur in a component formed portion upon automobile collision to easily break the components, so that the safety of passengers may be endangered. In addition, as the standards for the safety of passengers are increasing, the adoption of thick materials to ensure rigidity is steadily increasing, especially among some automobile companies.

- [0007]** Meanwhile, high-strength steel used as an automotive material includes, representatively, a dual phase steel (DP steel), a transformation induced plasticity steel (TRIP steel), a complex phase steel (CP steel), a ferrite-bainite steel (FB steel), and the like.

[0008] Since a DP steel which is an ultra-high tensile steel has a low yield ratio of about 0.5 to 0.6, the DP steel has an advantage in that it is easy to process, and has a second highest elongation after a TRIP steel. Thus, it is mainly applied to a door outer, a seat rail, a seat belt, a suspension, an arm, a wheel disc, and the like.

- [0009]** Since TRIP steel has a yield ratio in a range of 0.57 to 0.67, it is characterized by having excellent formability (high ductility), and is suitable for components requiring high formability such as a member, a roof, a seat belt, a bumper rail, and the like.

[0010] A CP steel is applied to a side panel, an underbody reinforcing material, and the like by a high elongation and bending processability together with a low yield ratio, and a FB steel has excellent hole expandability and is mainly applied to a suspension lower arm, a wheel disc, and the like.

- 40 **[0011]** Thereamong, a DP steel is mainly formed of ferrite having excellent ductility and a hard phase having high strength (martensite phase, bainite phase), and a trace amount of residual austenite may exist therein. The DP steel as such has low yield strength and high tensile strength to have a low yield ratio (YR), and has excellent characteristics such as a high processing hardening rate, high ductility, continuous yield behavior, aging resistance at room temperature, bake hardenability, and the like. In addition, when a fraction, a degree of recrystallization, distribution uniformity, and the like, of each phase are controlled, the steel may be manufactured as a high-strength steel having high hole expandability.

[0012] However, in order to secure ultra-high strength of a tensile strength of 980 MPa or more, the fraction of a hard phase such as a martensite phase which is favorable to strength improvement should be increased, and in this case, yield strength is increased to cause defects such as cracks during press forming.

- 50 **[0013]** In general, a DP steel for an automobile is manufactured into a final product by manufacturing a slab by steelmaking and continuous casting processes, subjecting the slab to [heating - rough rolling - finish hot rolling] to obtain a hot-rolled coil, and then performing an annealing process.

- [0014]** Here, an annealing process is a process performed mainly in the manufacture of a cold-rolled steel sheet, and the cold-rolled steel sheet is manufactured by pickling a hot-rolled coil to remove a surface scale, performing cold rolling to a certain reduction rate at room temperature, and then performing an annealing process, and, if necessary, an additional temper rolling process.

[0015] Since a cold-rolled steel sheet (cold-rolled material) obtained by cold rolling is in a very hardened state itself and is unsuitable for manufacturing components requiring processability, it may be softened by a heat treatment in a

continuous annealing furnace as a subsequent process to improve processability.

[0016] As an example, in the annealing process, a steel sheet (cold-rolled material) is heated to about 650 to 850°C in a heating furnace and the temperature thereof is maintained for a certain amount of time, thereby lowering hardness and improving processability through recrystallization and phase transformation phenomena.

[0017] A steel sheet which is not subjected to the annealing process has a high hardness, in particular, a high surface hardness and lacks processability, while a steel sheet subjected to an annealing process has a recrystallization structure, thereby having lowered hardness, yield point, and tensile strength to promote improvement of processability.

[0018] As a representative method of lowering the yield strength of a DP steel, ferrite is completely recrystallized in a heating process during continuous annealing to be manufactured into an equiaxed crystal form, so that austenite is produced and grows in a subsequent process to be the equiaxed crystal form, and thus, it is favorable for forming a small-sized and uniform austenite phase.

[0019] In the case of thick materials, a thickness of a hot-rolled steel sheet should be secured to be relatively thick in order to secure a certain reduction rate, so there is a problem in that a load during subsequent cold rolling is large and operability is lowered. If the reduction rate is low when manufacturing thick materials, structural nonuniformity due to non-recrystallization of ferrite during annealing increases and yield strength increases, and there is a problem in that yield strength increases, and processability deteriorates as directionality of cold rolling is maintained in the microstructure. Therefore, in the case of thick materials, material deviation in a thickness direction is bound to be large due to nature of dimensional characteristics, so a technology for homogenizing a material as much as possible is required to improve processability and usable properties.

[0020] Meanwhile, Patent Document 1 discloses that it is possible to secure hole expandability and elongation by forming fine precipitates using Ti, Mo, and the like, and including ferrite, bainite, and martensite phases as a microstructure.

[0021] However, the present document has problems with weldability and liquid metal embrittlement (LME) due to silicon excessively added to introduce carbon and bainite to form fine precipitates. In addition, there may still be a problem due to a difference in hardness between a soft phase and a hard phase, and as the bainite phase is formed in an excessive fraction for high hole expandability, resulting in a disadvantage in that it may be difficult to process due to high yield strength and elongation may be poor.

[0022] Considering the prior art described above, in order to simultaneously improve formability such as elongation, hole expandability, and the like, of thick high-strength steel, development of a plan which may lower yield strength and improve processability is required.

[0023] (Patent Document 1) Korean Patent Laid-Open Publication No. 10-2021-0095156.

Summary of Invention

Technical Problem

[0024] An aspect of the present disclosure is to provide, as a material suitable for an automotive structural member, or the like, a high-strength thick steel sheet having a low yield ratio and high strength, and excellent formability such as hole expandability through improved ductility, and a method for manufacturing the same.

[0025] An object of the present disclosure is not limited to the above description. The object of the present disclosure will be understood from the entire content of the present specification, and a person skilled in the art to which the present disclosure pertains will understand an additional object of the present disclosure without difficulty.

Solution to Problem

[0026] According to an aspect of the present disclosure, provided is a high-strength thick steel sheet having excellent hole expandability and ductility, the high-strength thick steel sheet including, by weight: 0.05 to 0.12% of carbon (C), 2.0 to 3.0% of manganese (Mn), 0.5% or less (excluding 0%) of silicon (Si), 1.0% or less (excluding 0%) of chromium (Cr), 0.1% or less (excluding 0%) of niobium (Nb), 0.1% or less (excluding 0%) of titanium (Ti), 0.003% or less (excluding 0%) of boron (B), 0.02 to 0.05% of aluminum (sol.Al), 0.05% or less (excluding 0%) of phosphorus (P), 0.01% or less (excluding 0%) of sulfur (S), and 0.01% or less (excluding 0%) of nitrogen (N), with a remainder of Fe and other unavoidable impurities,

[0027] wherein a steel sheet includes, by area fraction, 10 to 30% of ferrite, 10 to 25% of recrystallized ferrite bridge, and 20 to 30% of bainite, and residual martensite as a microstructure.

[0028] According to another aspect of the present disclosure, provided is a method for manufacturing a high-strength thick steel sheet having excellent hole expandability and ductility, the method for manufacturing a high-strength thick steel sheet having excellent hole expandability and ductility including: preparing a steel slab; heating the steel slab at a temperature within a range of 1100 to 1300°C; hot rolling the heated steel slab to manufacture a hot-rolled steel sheet; coiling the hot-rolled steel sheet at a temperature within a range of 400 to 700°C; cooling the hot-rolled steel sheet to

room temperature after the coiling; cold rolling the cooled hot-rolled steel sheet at a cold reduction rate of 55 to 80% to manufacture a cold-rolled steel sheet; continuously annealing the cold-rolled steel sheet; performing primary cooling to a temperature within a range of 650 to 700°C at an average cooling rate of 1 to 10°C/s after the continuous annealing; and performing secondary cooling to a temperature within a range of 450 to 500°C at an average cooling rate of 5 to 50°C/s after the primary cooling,

[0029] wherein the continuous annealing is performed in an equipment equipped with a heating zone, a soaking zone, and a cooling zone, and the cold-rolled steel sheet passes through a recrystallization zone in which the cold-rolled steel sheet is maintained at a temperature within a range of 600 to 700°C for 1 to 3 minutes when the temperature of the cold-rolled steel sheet is raised to a temperature within a range of the heating zone.

Advantageous Effects of Invention

[0030] As set forth above, according to the present disclosure, a thick steel sheet having improved formability and collision resistance due to excellent hole expandability despite having high strength may be provided.

[0031] As described above, the steel sheet of the present disclosure having improved formability may prevent processing defects such as cracks, wrinkles, or the like, during processing forming, and is thus suitable for being applied to structural parts requiring being processed into a complex shape. Furthermore, it is also effective in manufacturing a material having improved collision resistance to prevent defects such as cracks, or the like, from being formed when a car to which such components are applied inevitably collides.

Brief description of the Drawings

[0032]

FIG. 1 illustrates a heat history and phase transformation history during continuous annealing according to an embodiment of the present disclosure. In FIG. 1, it should be noted that a dotted line represents a heat history during conventional continuous annealing, and a solid line represents a heat history during continuous annealing according to the present disclosure.

FIG. 2 (a) illustrates a mechanism for forming a void in a structure, and FIG. 2(b) illustrates a mechanism for strengthening an interface in a structure according to an embodiment of the present disclosure.

FIGS. 3 and 4 illustrate images of microstructures of Comparative Example (FIG. 3) and Inventive Example (FIG. 4) according to an embodiment of the present disclosure (an arrow in FIG. 4 indicates a recrystallized ferrite bridge structure).

Best Mode for Invention

[0033] The inventors of the present disclosure conducted intensive research in order to develop a material having a formability level which may be suitably used in components and the like requiring processing to a complicated shape among automotive materials.

[0034] In particular, in thick steel sheets for automobiles, which inevitably have a relatively low cold rolling reduction rate, the present inventors confirmed that the goal may be achieved by deriving a composition of a structure that can increase crack resistance between hard phases and refining a hard phase favorable to preventing formation and propagation of voids and controlling a crystal grain shape, thereby completing the present disclosure.

[0035] In particular, the present disclosure introduces a recrystallized ferrite bridge having a structure connecting the hard phases to each other so that unidirectionality of the hard phases is removed, and has technical significance in optimizing an alloy composition and manufacturing conditions forming the structure.

[0036] Hereinafter, the present disclosure will be described in detail.

[0037] According to an aspect of the present disclosure, a high-strength thick steel sheet having excellent hole expandability and ductility may be provided, the high-strength thick steel sheet including, by weight: 0.05 to 0.12% of carbon (C), 2.0 to 3.0% of manganese (Mn), 0.5% or less (excluding 0%) of silicon (Si), 1.0% or less (excluding 0%) of chromium (Cr), 0.1% or less (excluding 0%) of niobium (Nb), 0.1% or less (excluding 0%) of titanium (Ti), 0.003% or less (excluding 0%) of boron (B), 0.02 to 0.05% of aluminum (sol.Al), 0.05% or less (excluding 0%) of phosphorus (P), 0.01% or less (excluding 0%) of sulfur (S), and 0.01% or less (excluding 0%) of nitrogen (N), with a remainder of Fe and other unavoidable impurities.

[0038] Hereinafter, a reason for limiting the alloy composition of the high-strength thick steel sheet provided in the present disclosure as described above will be described in detail.

[0039] Meanwhile, in the present disclosure, unless otherwise specified, a content of each element is based on weight, and a ratio of structure is based on area.

Carbon (C): 0.05 to 0.12%

[0040] Carbon (C) is an important element which is added for solid solution strengthening, and is bonded to a precipitation element to form a fine precipitate, thereby contributing to improving strength of steel.

[0041] When the content of C exceeds 0.12%, hardenability increases and strength increases excessively as martensite is formed during cooling in the manufacture of steel, thereby excessively increasing strength, while causing a decrease in elongation. In addition, weldability may be poor, so that weld defects may occur in processing into components. Meanwhile, when the content of C is less than 0.05%, it is difficult to secure a target level of strength.

[0042] Therefore, C may be included in an amount of 0.05 to 0.12%. More favorably, C may be included in an amount of 0.06% or more and 0.10% or less.

Manganese (Mn): 2.0 to 3.0%

[0043] Manganese (Mn) is an element which precipitates sulfur (S) in steel as MnS to prevent hot brittleness by production of FeS, and is favorable to solid solution strengthening of steel.

[0044] When a content of Mn is less than 2.0%, the effects described above may not be obtained, and it is difficult to secure a target level of strength. However, when the Mn content exceeds 3.0%, problems in weldability, hot rolling, and the like are likely to occur, and at the same time, there is a risk that ductility may decrease as martensite is more easily formed by an increase in hardenability. In addition, a Mn-band (Mn oxide band) may be excessively formed in the structure to increase the risk of defects such as processing cracks. Further, a Mn oxide is eluted on the surface during annealing to greatly deteriorate plating properties.

[0045] Therefore, Mn may be included in an amount of 2.0 to 3.0%, and more favorably, Mn may be included in an amount of 2.2% or more and 2.8% or less.

Silicon (Si): 0.5% or less (excluding 0%)

[0046] Silicon (Si) is a ferrite stabilizing element, and promotes ferrite transformation to be favorable to securing a target level of ferrite fraction. In addition, it has good solid solution strengthening ability to be effective to increase strength of ferrite, and is an element useful for securing strength while not decreasing ductility.

[0047] When a content of Si exceeds 0.5%, the solid solution strengthening effect is excessive so that ductility is rather decreased, and surface scale defects are caused to adversely affect plating surface quality. In addition, phosphatability is deteriorated.

[0048] Therefore, Si may be included in an amount of 0.5% or less, and 0% may be excluded. More favorably, Si may be included in an amount of 0.1% or more.

Chromium (Cr): 1.0% or less (excluding 0%)

[0049] Chromium (Cr) is an element facilitating formation of a bainite phase by exerting a hardenability effect during cooling, and is an element which forms a fine carbide while suppressing formation of a martensite phase during an annealing heat treatment, thereby contributing to strength improvement.

[0050] In addition, in the present disclosure, by containing Cr at an appropriate level, Cr acts as a ferrite stabilizing element during heating to delay a reaction of austenite phase transformation and phase transformation begins at a higher temperature, Cr stays for a long time in a region (Trex~A1) where only recrystallization occurs during heating. As a result thereof, a recrystallized ferrite bridge structure may be secured.

[0051] When the Cr content exceeds 1.0%, the recrystallized ferrite bridge, which is intended may not be formed, thereby reducing ductility and hole expandability of steel, and when a carbide is formed at a grain boundary, strength and an elongation may be deteriorated. In addition, manufacturing costs may be increased.

[0052] Therefore, Cr may be included in an amount of 1.0% or less, and 0% may be excluded. More favorably, Cr may be included in an amount of 0.01% or more.

Niobium (Nb): 0.1% or less (excluding 0%)

[0053] Niobium (Nb) is an element which is segregated at an austenite grain boundary, and suppresses coarsening of austenite crystal grains during an annealing heat treatment, and forms a fine carbide to contribute to strength improvement.

[0054] When a content of Nb exceeds 0.1%, a coarse carbide is precipitated, strength and an elongation may be decreased by a reduced carbon amount in steel, and manufacturing costs may be increased.

[0055] Therefore, Nb may be included in an amount of 0.1% or less, and 0% may be excluded.

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Titanium (Ti): 0.1% or less (excluding 0%)

[0056] Titanium (Ti) is an element forming a microcarbide, and contributes to securing yield strength and tensile strength. In addition, Ti precipitates N in steel as TiN to suppress the formation of AlN by Al which is unavoidably present in steel, and thus, reduces the possibility of cracks during continuous casting.

[0057] When a content of Ti exceeds 0.1%, a coarse carbide is precipitated, and strength and an elongation may be decreased by a reduced carbon amount in steel. In addition, nozzle clogging may occur during continuous casting, and manufacturing costs may be increased.

[0058] Therefore, Ti may be included in an amount of 0.1% or less, and 0% may be excluded.

Boron (B): 0.003% or less (excluding 0%)

[0059] Boron (B) is an element which delays transformation of austenite into pearlite during a cooling process after an annealing heat treatment, but when a content of B exceeds 0.003%, B may excessively concentrate on the surface, resulting in deterioration of plating adhesion.

[0060] Therefore, B may be included in an amount of 0.003% or less, and 0% may be excluded considering an avoidably added level.

Aluminum (Sol.Al): 0.02 to 0.05%

[0061] Aluminum (sol.Al) is an element added for an effect of refining a grain size of steel and for deoxidation. When a content of aluminum (sol.Al) is less than 0.02%, aluminum killed steel may not be manufactured in a stable state. On the other hand, when the aluminum content exceeds 0.05%, crystal grains are refined and the strength is improved, but a risk of surface defects in a plated steel sheet increases due to excessive formation of inclusions during steelmaking.

[0062] Therefore, aluminum (sol.Al) may be included in an amount of 0.02 to 0.05%.

Phosphorus (P): 0.05% or less (excluding 0%)

[0063] Phosphorus (P) is a substitutional element having the greatest solid solution strengthening effect, and is an element which improves in-plane anisotropy and is favorable for securing strength without significantly reducing formability. However, when P is excessively added, a possibility of brittle fracture occurrence is greatly increased, so that a possibility of sheet fracture of a slab during hot rolling is increased and plating surface properties are deteriorated.

[0064] Therefore, in the present disclosure, the P content may be controlled to be 0.05% or less, and 0% may be excluded considering an avoidably added level.

Sulfur (S): 0.01% or less (excluding 0%)

[0065] Sulfur (S) is an element which is unavoidably added as an impurity element in steel, and deteriorates ductility, and thus, it is preferred to manage the content as low as possible. In particular, S has a problem of increasing a possibility of red brittleness occurrence, it is preferred to control the content to be 0.01% or less. However, considering the unavoidably added level during the manufacturing process, 0% may be excluded.

Nitrogen (N): 0.01% or less (excluding 0%)

[0066] Nitrogen (N) is a solid solution strengthening element, but a content of nitrogen (N) exceeds 0.01%, a risk of brittleness occurrence increases, and is bonded to Al in steel and precipitates as TiN to deteriorate casting quality.

[0067] Therefore, N may be included in an amount of 0.01 or less, and considering the unavoidably added level during the manufacturing process, 0% may be excluded.

[0068] The remaining component of the present disclosure is iron (Fe). However, since in the common manufacturing process, unintended impurities may be inevitably incorporated from raw materials or the surrounding environment, the component may not be excluded. Since these impurities are known to any person skilled in the common manufacturing process, the entire contents thereof are not particularly mentioned in the present specification.

[0069] The steel sheet of the present disclosure having the above-described alloy composition may have a microstructure including ferrite, which is a soft phase, and bainite and martensite phases, which are hard phases, and a recrystallized ferrite bridge structure formed by connecting the hard phases.

[0070] In the present disclosure, the biggest change in microstructure due to formation of the recrystallized ferrite bridge is a loss of rolling directionality of existing ferrite and a degree of connection around the hard phases is large. In addition, a formation location of reverse transformation austenite is reduced during formation of a recrystallized ferrite

bridge during heating and formation of austenite at high temperatures is delayed, a secondary phase having a smaller size after cooling may be generated. A non-recrystallized ferrite region is an elongated structure with rolling directionality and remains as an irregular rough interface, and a recrystallized ferrite bridge grain boundary has a smooth interface having a polygonal shape. A method of determining the recrystallized ferrite bridge may be divided into, for example,

an electron backscatter diffraction orientation (EBSD), or may be optically divided by etching with an aqueous hydrogen peroxide solution (ex. 140 ml of distilled water, 100 ml of hydrogen peroxide, 4 g of oxalic acid, 2 ml of sulfuric acid, 1.5 ml of hydrofluoric acid).

[0071] Specifically, the steel sheet of the present disclosure may include a ferrite phase in an area fraction of 10 to 30%, a recrystallized ferrite bridge phase in an area fraction of 10 to 25%, and 20 to 30% of bainite, which is a hard phase, and a remainder of martensite phase. In addition, the steel sheet may include a trace amount of residual austenite phase.

[0072] In the present disclosure, the recrystallized ferrite bridge phase is a structure that is advantageous in suppressing propagation of voids generated along a grain boundary of the hard phase by resolving the unidirectionality of the hard phase, and is a structure that is separated from existing polygonal ferrite.

[0073] In addition, the recrystallized ferrite bridge is a structure that is separated from general recrystallized ferrite, and is relatively coarse, preferably having an average size of 1 to 6 μm based on an equivalent circular diameter. When the size of the recrystallized ferrite bridge phase is less than 1 μm , it is difficult to resolve directionality of the hard phase, so the desired effect may not be obtained. On the other hand, when the size thereof exceeds 6 μm , the recrystallized ferrite bridge phase becomes an excessively coarse structure, so that there is a concern that physical properties such as strength, or the like, may be impaired.

[0074] As shown in FIG. 2, when the hard phase is formed to have directionality (a), connection of voids formed along the grain boundaries becomes easier, thereby facilitating the propagation of cracks. On the other hand, when the structure (b) intended in the present disclosure, especially, the recrystallized ferrite bridge phase is formed as a structure connecting the hard phases to each other while removing the unidirectionality of the hard phases, it becomes difficult for voids to coalesce along the grain boundaries, which has an effect of greatly suppressing occurrence and propagation of cracks.

[0075] When a fraction of this recrystallized ferrite bridge phase is excessively high, the fraction of the hard phase becomes relatively low, making it impossible to secure the target level of strength. Considering this, the recrystallized ferrite bridge phase may be included in an amount of 25% or less. On the other hand, when the fraction is less than 10%, the above-described effects (removal of hard phase unidirectionality, suppression of void propagation, and the like) cannot be sufficiently obtained, resulting in inferior hole expandability.

[0076] In other words, the present invention has technical significance in that formability may be further improved by introducing a recrystallized ferrite bridge phase in addition to the soft ferrite phase and the hard phase bainite phase and martensite phase and controlling the shape and distribution of the recrystallized ferrite bridge phase.

[0077] When a fraction of the ferrite phase is less than 10%, it is disadvantageous to secure the ductility of the steel. On the other hand, when the fraction exceeds 30%, the fraction of the hard phase is relatively low, making it difficult to secure the target level of strength.

[0078] When a fraction of the bainite phase is less than 20%, not only is it difficult to secure strength, but there is also a problem in that a difference in hardness between a soft phase and a martensite phase increases. On the other hand, when the fraction exceeds 30%, a fraction of the soft phase decreases, making it difficult to secure ductility.

[0079] Among the structures, excluding the ferrite phase, recrystallized ferrite bridge phase, and bainite phase, a fraction of the martensite phase is not specifically limited, but in order to secure ultra-high strength of 980 MPa or more, the martensite phase may be included in an area fraction of 15% or more. However, when the fraction of the martensite phase exceeds 60%, ductility decreases, making it difficult to secure the target level of formability.

[0080] Meanwhile, it is favorable that the fraction of the residual austenite phase does not exceed 3%, and even if it is 0%, it should be noted that there is no problem in securing the intended physical properties.

[0081] The high-strength thick steel sheet of the present disclosure having the above-described microstructure may have high strength and high ductility having a tensile strength of 980 MPa or more, a yield strength of 550 to 700 MPa, and an elongation (total elongation) of 14% or more.

[0082] In addition, the steel plate has a hole expansion ratio (HER) of 30% or more, thereby providing excellent resistance to cracks that may occur during processing and resistance to impact fracture.

[0083] The high-strength thick steel sheet of the present disclosure may have a thickness of 1 to 3 mm, and more preferably 1.5 to 2.5 mm.

[0084] Hereinafter, a method for manufacturing a high-strength and thick steel sheet having excellent hole expandability and ductility according to another aspect of the present disclosure will be described in detail.

[0085] In brief, in the present disclosure, a target steel sheet may be manufactured by performing processes of [steel slab heating - hot rolling - coiling - cold rolling - continuous annealing], and each process will be described in detail.

[Steel slab heating]

[0086] First, a steel slab satisfying the alloy composition described above may be prepared, and then heated.

[0087] The present process is performed to smoothly perform a subsequent hot rolling process, and is performed to sufficiently obtain physical properties of the target steel sheet. In the present disclosure, conditions of the heating process are not particularly limited, and may be common conditions. As an example, the heating process may be performed at a temperature within a range of 1100 to 1300°C.

[Hot rolling process]

[0088] The steel slab heated as described above may be hot rolled to manufacture a hot-rolled steel sheet, and herein, finish hot rolling may be performed at an outlet temperature of Ar3 or higher to 1000°C or lower.

[0089] When an outlet temperature is lower than Ar3 in the finish hot rolling, hot deformation resistance is rapidly increased, and top, tail, and edge portions of a hot-rolled coil become a single-phase region to increase in-plane anisotropy, so that formability may be deteriorated. Meanwhile, when the temperature is higher than 1000°C, a rolling load is relatively decreased, so that it is favorable to productivity, but a thick oxide scale may occur.

[0090] More specifically, the finish hot rolling may be performed at a temperature within a range of 760 to 940°C.

[Coiling]

[0091] The hot-rolled steel sheet manufactured as described above may be coiled to a coil shape.

[0092] The coiling may be performed at a temperature within a range of 400 to 700°C. When a coiling temperature is lower than 400°C, an increase in excessive strength of the hot-rolled steel sheet is caused due to excessive formation of martensite or recrystallized ferrite bridge phases, and problems such as poor shape due to a load during subsequent cold rolling may be caused. However, when the coiling temperature is higher than 700°C, a surface scale is increased to deteriorate pickling properties.

[Cooling]

[0093] It is preferred that the coiled hot-rolled steel sheet is cooled to room temperature at an average cooling rate of 0.1°C/s or less (excluding 0°C/s). In this case, the coiled hot-rolled steel sheet may be cooled after being subjected to processes such as transfer and stacking, and it should be noted that the process before cooling is not limited thereto.

[0094] As such, the coiled hot-rolled steel sheet is cooled at a constant speed, thereby obtaining a hot-rolled steel sheet in which a carbide which is a nucleation site of austenite is finely dispersed.

[Cold rolling]

[0095] The hot-rolled steel sheet coiled as described above may be cold rolled to manufacture a cold-rolled steel sheet, and in the present disclosure, the cold rolling may be performed at a cold reduction rate of 55 to 80%.

[0096] In the present disclosure, recrystallization of ferrite may be further promoted in a heating section during a subsequent continuous annealing process while applying an appropriate level of cold reduction rate during cold rolling, and therefrom, formation of fine ferrite may be induced so that austenite formed at a ferrite grain boundary may also be formed to be small and uniform.

[0097] When the cold reduction rate in the cold rolling is less than 55%, ferrite recrystallization is delayed, so that it is difficult to obtain a fine and uniform austenite phase, but when the cold reduction rate exceeds 80%, yield strength is excessively reduced due to excessive recrystallization so that a target level of strength may not be secured. More favorably, the cold rolling may be performed at a cold reduction rate of 78% or less.

[0098] In the present disclosure, the cold reduction rate may be realized not only with a high rolling capacity of ZRM equipment (e.g., at a level of 5000KN/mm) from a hot-rolled thick material having a certain thickness, but also include a process of achieving a target reduction rate by repeated rolling by using a reversing mill. As a non-limiting example, the hot-rolled thick material may have a thickness of 4 to 8 mm, and when the hot-rolled thick material has a thickness of 6 mm or more, it should be noted that a cold rolling process using a reversing mill may be performed.

[0099] The reversing mill is a type of rolling mill generally used for rolling thin materials, and refers to a rolling mill that rolls while reciprocating a material between a pair of rolls, and when reciprocating the material, one way may be set 1 pass.

[0100] In the present disclosure, the hot-rolled steel sheet may be pickled before the cold rolling, and it should be noted that the pickling treatment process may be performed by a conventional method.

[Continuous annealing]

[0101] It is preferred that the cold-rolled steel sheet manufactured as described above is continuously annealed. The continuous annealing treatment may be performed in a continuous annealing line (CAL), as an example.

[0102] Usually, the continuous annealing line (CAL) may be formed of [heating zone -soaking zone - cooling zone (slow cooling zone and rapid cooling zone) - overaging zone], and after the cold-rolled steel sheet is charged into the continuous annealing line as such, the steel sheet is heated to a certain temperature in the heating section, and after a target temperature is reached, the steel sheet is maintained in the soaking zone for a certain period of time.

[0103] In the present disclosure, a temperature of the heating zone and the soaking zone may be controlled to be the same during the continuous annealing, which means that an end temperature of the heating zone and a starting temperature of the soaking zone are controlled to be the same (FIG. 1).

[0104] Specifically, the temperature of the heating zone and the soaking zone can be controlled to be 790 to 850°C.

[0105] In addition, when the temperature of the soaking zone is lower than 790°C, it is economically disadvantageous because excessive cooling is required at the end temperature of the heating zone, and there is a risk that an amount of heat for recrystallization may be insufficient. On the other hand, when the temperature is higher than 850°C, a fraction of austenite may be excessive and there is a risk that formability may decrease due to an increase in the hard phase during cooling.

[0106] When the temperature of the soaking zone within the above-described temperature range is increased, the fraction of the hard phase in the final structure is increased to increase a yield strength, and the same time, a difference in hardness between the phases is lowered by introducing bainite to improve a hole expansion ratio.

[0107] Meanwhile, in the present disclosure, by causing sufficient recrystallization in the annealing process, generation of recrystallized ferrite bridge is induced.

[0108] Specifically, in the present disclosure, a recrystallization zone in which the cold-rolled steel sheet is maintained at an intermediate temperature for a certain period of time when the temperature is raised to a temperature within a range of the heating zone, and more preferably, a process in which the cold-rolled steel sheet is maintained at a temperature within a range of 600 to 700 °C for 1 to 3 minutes is preferably performed (dotted line graph in FIG. 2).

[0109] When the temperature of the recrystallization zone is lower than 600°C or a holding time is less than 1 minute, recrystallization of ferrite is not sufficient, so a recrystallized ferrite bridge phase may not be formed at the target fraction. On the other hand, when the temperature is higher than 700°C or the holding time exceeds 3 minutes, there is a risk of decreasing strength due to excessive recrystallization and decreasing physical properties due to grain coarsening.

[0110] In the present disclosure, by introducing a recrystallized ferrite bridge phase along with an appropriate fraction of hard and soft phases into a final microstructure through the recrystallization zone process, an effect of improving processability may be obtained by strengthening crack toughness, that is crack resistance, while maintaining the strength.

[Stepwise cooling]

[0111] The cold-rolled steel sheet subjected to continuous annealing as described above, may be cooled, thereby forming a target structure, and in this case, it is preferred to perform cooling stepwise.

[0112] In the present disclosure, the stepwise cooling may be formed of primary cooling - secondary cooling, and specifically, primary cooling may be performed at a temperature within a range of 650 to 700°C at an average cooling rate of 1 to 10°C/s after the continuous annealing, and then secondary cooling may be performed at a temperature within a range of 400 to 500°C at an average cooling rate of 5 to 50°C/s.

[0113] In this case, the primary cooling may be performed more slowly than the secondary cooling, thereby suppressing plate shape defects due to a rapid temperature drop during the secondary cooling, which is a relatively rapid cooling section.

[0114] When the end temperature in the primary cooling is lower than 650°C, the diffusion activity of carbon is low due to the too low temperature, so that a carbon concentration in ferrite is increased, but as the carbon concentration in austenite is decreased, so that a fraction of a hard phase is excessive to increase a yield ratio, resulting in a higher tendency to crack occurrence during processing. In addition, the cooling rates between the soaking zone and the cooling zone (slow cooling zone) are excessively high, so that there is a problem in that the shape of the sheet is non-uniform. When the end temperature is higher than 700°C, there is a disadvantage in that an excessively high cooling rate is required in the subsequent cooling (secondary cooling).

[0115] In addition, when the average cooling rate in the primary cooling exceeds 10°C/s, carbon diffusion may not sufficiently occur. Meanwhile, considering the productivity, the primary cooling may be performed at an average cooling rate of 1°C/s or more.

[0116] As described above, after completing the primary cooling, rapid cooling (secondary cooling) may be performed at a cooling rate at or above a certain level. In this case, when the secondary cooling end temperature is lower than 450°C, a cooling deviation in a width direction and a length direction of the steel sheet occur, so that a plate shape may

be deteriorated. On the other hand, when the temperature is higher than 500°C, a hard phase may not be sufficiently secured, so that the strength may be lowered.

[0117] In addition, the average cooling rate in the secondary cooling is less than 5°C/s, a fraction of a soft phase may be excessive, but when the average cooling rate exceeds 50°C/s, the hard phase may be rather insufficient.

[0118] Meanwhile, if necessary, when the stepwise cooling is completed, an overaging treatment may be performed.

[0119] The overaging treatment is a process of maintaining for a certain period of time after the secondary cooling end temperature, and a uniform heat treatment in a width direction and a length direction of the coil is performed, thereby improving shape quality. To this end, the overaging treatment may be performed for 200 to 800 seconds.

[0120] Since the overaging treatment may be performed immediately after the end of the secondary cooling, the temperature may be the same as the secondary cooling end temperature, may be performed within the secondary cooling end temperature range, or may be performed at a lower temperature thereof. More favorably, it should be noted that the overaging treatment may be performed at a temperature within a range of 300 to 450 °C.

[0121] The high-strength thick steel sheet of the present disclosure manufactured as described above is formed of a hard phase and a soft phase as a microstructure, and in particular, ferrite recrystallization is excessively increased by an optimized cold rolling and annealing process, thereby having a structure in which a martensite phase, which is a hard phase is uniformly distributed in a finally recrystallized ferrite matrix. In addition, by introducing a relatively coarse recrystallized ferrite bridge phase to connect the hard phase, crack resistance during processing may be increased.

[0122] Thus, the thick steel sheet of the present disclosure may secure excellent formability such as hole expandability, or the like, by securing a low yield ratio and high ductility, even with a high strength of a tensile strength of 980 MPa or more.

Best Mode for Invention

[0123] Hereinafter, the present disclosure will be specifically described through the following Examples. However, it should be noted that the following Examples are only for describing the present disclosure in detail by illustration, and are not intended to limit the right scope of the present disclosure. The reason is that the right scope of the present disclosure is determined by the matters described in the claims and reasonably inferred therefrom.

(Example)

[0124] After manufacturing a steel slab having the alloy composition shown in the following Table 1, each steel slab was heated at 1200°C for 1 hour and then subjected to finish hot rolling at a finish rolling temperature of 880 to 920°C to manufacture a hot-rolled steel sheet. Thereafter, each hot-rolled steel sheet was coiled at 650°C, and then cooled to room temperature at a cooling rate of 0.1°C/s. Thereafter, the coiled hot-rolled steel sheet was subjected to cold rolling and continuous annealing under the conditions shown in the following Table 2, was then subjected to stepwise cooling (first - second), and was then subjected to an overaging treatment at 360°C for 520 seconds to manufacture a final steel sheet having a thickness of 1.8mm.

[0125] In this case, first cooling was performed at an average cooling rate of 3°C/s, and second cooling was performed at an average cooling rate of 20°C/s, in the stepwise cooling.

[0126] The microstructure of each steel sheet manufactured as described above was observed, and processing process utilization properties indices such as tensile and processing characteristics and hole expansion ratio were evaluated were evaluated, and the results thereof were shown in the following Table 3.

[0127] In this case, a tensile test for each specimen was performed at a strain rate of 0.01/s after collecting a tensile specimen of a JIS No. 5 size in a vertical direction to a rolling direction.

[0128] Meanwhile, a test of measuring a hole expansion ratio (HER) was performed in accordance with an ISO 16630 standard. Specifically, when a circular hole was punched in a test specimen and then expanded using a conical punch, an amount of hole expansion until cracks occurring at an edge of the hole penetrated in a thickness direction was expressed as a ratio to an initial hole. In this case, a specimen dimension was 120 mm × 120 mm, a clearance was 12%, a diameter of a punched hole was 10 mm, a load of a punched hole was 20 tons, and a test speed was 12 mm/min.

[0129] Further, among structural phases, a bainite phase, corresponding to a hard phase, was observed through pircral etching, and a martensite phase was observed at 2000X magnification and 5000X magnification by SEM after nital etching.

[0130] In addition, each fraction of a ferrite phase and a recrystallized ferrite bridge phase were measured by SEM and using an image analyzer program after nital etching.

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[Table 1]

Steel No.	Alloy composition (weight %)										
	C	Si	Mn	P	S	Sol. Al	Nb	Ti	Cr	N*	B*
1	0.071 8	0.404	2.303	0.0079	0.002 1	0.038	0.051	0.0203	0.814	39	26
2	0.0997	1.095	2.759	0.0089	0.0008	0.031	0.003	0.0025	0.015	39	3

N*, B* is represented in weight ppm.

[Table 2]

Steel No.	Cold rolling	Continuous annealing					Division
		Cold reduction rate(%)	Recrystallization temperature(°C) /time (min.)	Soaking zone temperature (°C)	Primary cooling end temperature (°C)	secondary cooling end temperature (°C)	
1	38	-		790	650	450	Comparative Example 1
1	55	-		790	650	450	Comparative Example 2
1	64	-		790	650	450	Comparative Example 3
1	78	-		790	650	450	Comparative Example 4
1	38	700/1min.		790	650	450	Comparative Example 5
1	55	700/1min.		790	650	450	Inventive Example 1
1	64	700/1min.		790	650	450	Inventive Example 2
1	78	700/1min.		790	650	450	Inventive Example 3
1	38	-		850	650	450	Comparative Example 6
1	55	-		850	650	450	Comparative Example 7
1	64	-		850	650	450	Comparative Example 8
1	78	-		850	650	450	Comparative Example 9
1	38	700/1min.		850	650	450	Comparative Example 10
1	55	700/1min.		850	650	450	Inventive Example 4
1	64	700/1min.		850	650	450	Inventive Example 5
1	78	700/1min.		850	650	450	Inventive Example 6

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(continued)

Steel No.	Cold rolling	Continuous annealing				Division
	Cold reduction rate(%)	Recrystallization zone temperature(°C) /time (min.)	Soaking zone temperature (°C)	Primary cooling end temperature (°C)	secondary cooling end temperature (°C)	
2	38	-	790	650	300	Comparative Example 11
2	55	-	790	650	300	Comparative Example 12
2	64	-	790	650	300	Comparative Example 13
2	78	-	790	650	300	Comparative Example 14

[Table 3]

Division	Microstructure					Mechanical properties				
	Ferrite (area %)	Recrystallized ferrite bridge		Bainite (area %)	Marten site (area %)	YS (MPa)	TS (MPa)	YR (YS/T S)	EI (%)	HER (%)
		fraction (area %)	size (μm)							
Comparative Example 1	29.0	4.3	1.72	28.1	38.6	758.7	1136.7	0.67	9.2	22.5
Comparative Example 2	31.8	4.7	1.86	26.3	37.2	684.6	1085.6	0.63	10.8	24.3
Comparative Example 3	32.5	5.3	1.91	25.7	36.5	687.7	1103.2	0.62	12.2	25.7
Comparative Example 4	39.3	6.1	2.05	24.6	30.0	568.0	1022.7	0.56	15.0	29.5
Comparative Example 5	35.6	7.2	2.42	23.8	33.4	687.4	1057.3	0.65	13.0	30.7
Inventive Example 1	29.8	10.7	2.10	20.1	39.4	597.3	992.7	0.60	15.1	34.5
Inventive Example 2	27.4	14.1	2.62	24.9	33.6	582.5	985.6	0.59	16.6	40.0
Inventive Example 3	25.8	17.6	2.91	24.3	32.3	559.6	980.9	0.57	16.0	42.1
Comparative Example 6	20.4	5.9	3.03	38.1	35.6	723.1	1053.7	0.69	11.5	43.4
Comparative Example 7	23.9	6.5	3.11	36.2	33.4	713.4	1053.7	0.68	11.8	43.4
Comparative Example 8	21.3	7.2	3.28	37.3	34.2	716.0	1060.4	0.68	11.0	44.3

(continued)

Division	Microstructure					Mechanical properties				
	Ferrite (area %)	Recrystallized ferrite bridge		Bainite (area %)	Marten site (area %)	YS (MPa)	TS (MPa)	YR (YS/T S)	EI (%)	HER (%)
		fraction (area %)	size (μm)							
Comparative Example 9	23.5	9.1	3.34	34.6	32.8	710.6	1048.9	0.68	11.0	37.0
Comparative Example 10	26.6	9.7	3.52	31.4	32.3	658.7	1017.4	0.65	13.4	48.5
Inventive Example 4	18.2	23.3	3.65	27.1	31.4	645.3	1000.4	0.65	14.5	40.1
Inventive Example 5	16.4	23.8	4.02	28.2	31.6	658.1	1012.8	0.65	14.2	50.8
Inventive Example 6	15.5	24.7	4.33	29.1	30.7	642.3	992.5	0.65	14.1	52.4
Comparative Example 11	22.6	2.1	2.61	30.7	44.8	786.4	1089.2	0.72	11.5	34.8
Comparative Example 12	20.1	3.5	2.79	33.2	43.2	790.3	1077.6	0.73	11.4	40.9
Comparative Example 13	26.5	5.9	2.90	26.7	40.9	710.5	1057.4	0.67	12.2	27.0
Comparative Example 14	24.5	6.6	2.98	27.8	41.1	705.7	1049.2	0.67	12.4	38.1
YS: Yield Strength, TS: Tensile Strength, YR: Yield Ratio, EI: total Elongation										

[0131] As shown in Tables 1 to 3, in Inventive Examples 1 to 6 in which the steel alloy composition and the manufacturing conditions, in particular, a cold rolling and a continuous annealing process satisfied all of the suggestions in the present disclosure, a hard phase was formed by being connected thereto by a recrystallized ferrite bridge phase due to sufficient recrystallization of ferrite in an annealing process after cold rolling. Accordingly, it had high strength, yield strength appropriate for plate processing, and excellent elongation. In addition, it could be confirmed that the hole expandability was excellent due to homogeneous distribution of the hard phase, so that a target level of formability may be secured.

[0132] On the other hand, in Comparative Examples 1 to 4 and Comparative Examples 6 to 9, not passing through a recrystallization zone in the heating process during continuous annealing during the steel sheet manufacturing process, a recrystallized ferrite bridge phase was insufficient as recrystallization did not occur sufficiently. Thereamong, in Comparative Examples 1 to 4 in which a continuous annealing temperature was relatively low, and at least one physical property of elongation and hole expandability was inferior, and in Comparative Examples 6 to 9 in which a continuous annealing temperature was relatively high, yield strength was excessively high and elongation was inferior due to excessive formation of a bainite phase.

[0133] In Comparative Examples 5 and 10, sufficient austenite stability was illustrated to secure an annealing temperature and strength for recrystallization driving, but recrystallization did not occur sufficiently due to an insufficient reduction rate and a uniform structure was not formed, resulting in inferior elongation and relatively high yield strength.

[0134] In addition, Comparative Examples 11 to 14, in which a second cooling temperature was very low, had an excessively high yield strength, resulting in a high risk of cracks occurring during processing, and the elongation was inferior due to the absence of a recrystallized ferrite bridge phase.

[0135] FIG. 3 illustrates images of the microstructure of Comparative Examples 1, 4 to 5, and 9, and FIG. 4 illustrates images of the microstructure of Inventive Examples 1, 3 to 4, and 6.

[0136] As illustrated in FIG. 3, in Comparative Examples 1, 4, and 9, a recrystallization zone process was not introduced during a temperature increase process during continuous annealing, so a hard phase connection structure by the recrystallized ferrite bridge could hardly be confirmed. In addition, in Comparative Example 5, a fraction of the recrystal-

lization zone was low due to an insufficient reduction rate, and as recrystallization was insufficient due to low driving force, a structure in which hard phases gathered together was formed, and a structure having with low crack propagation resistance was formed.

[0137] On the other hand, as illustrated in FIG. 4, in Invention Examples, a relatively coarse recrystallized ferrite bridge phase was observed through the recrystallization zone process, and it can be seen that unidirectionality of the hard phase is removed by this phase.

Claims

1. A high-strength thick steel sheet having excellent hole expandability and ductility comprising, by weight:

0.05 to 0.12% of carbon (C), 2.0 to 3.0% of manganese (Mn), 0.5% or less (excluding 0%) of silicon (Si), 1.0% or less (excluding 0%) of chromium (Cr), 0.1% or less (excluding 0%) of niobium (Nb), 0.1% or less (excluding 0%) of titanium (Ti), 0.003% or less (excluding 0%) of boron (B), 0.02 to 0.05% of aluminum (sol.Al), 0.05% or less (excluding 0%) of phosphorus (P), 0.01% or less (excluding 0%) of sulfur (S), and 0.01% or less (excluding 0%) of nitrogen (N), with a remainder of Fe and other unavoidable impurities, wherein the steel sheet includes, by area fraction, 10 to 30% of ferrite, 10 to 25% of recrystallized ferrite bridge, and 20 to 30% of bainite, and residual martensite as a microstructure.

2. The high-strength thick steel sheet having excellent hole expandability and ductility of claim 1, wherein the recrystallized ferrite bridge has an average equivalent circular diameter of 1 to 6 μm .

3. The high-strength thick steel sheet having excellent hole expandability and ductility of claim 1, wherein the steel sheet has a martensite phase in an area fraction of 15% or more.

4. The high-strength thick steel sheet having excellent hole expandability and ductility of claim 1, wherein the steel sheet has a residual austenite phase in an area fraction of 3% or less (including 0%).

5. The high-strength thick steel sheet having excellent hole expandability and ductility of claim 1, wherein the steel sheet has a tensile strength of 980MPa or more, a yield strength of 550 to 700 MPa, and a total elongation of 14% or more.

6. The high-strength thick steel sheet having excellent hole expandability and ductility of claim 1, wherein the steel sheet has a hole expansion ratio (HER) of 30% or more.

7. The high-strength thick steel sheet having excellent hole expandability and ductility of claim 1, wherein the steel sheet has a thickness of 1 to 3 mm.

8. A method for manufacturing a high-strength thick steel sheet having excellent hole expandability and ductility comprising by weight:

preparing a steel slab including by weight, 0.05 to 0.12% of carbon (C), 2.0 to 3.0% of manganese (Mn), 0.5% or less (excluding 0%) of silicon (Si), 1.0% or less (excluding 0%) of chromium (Cr), 0.1% or less (excluding 0%) of niobium (Nb), 0.1% or less (excluding 0%) of titanium (Ti), 0.003% or less (excluding 0%) of boron (B), 0.02 to 0.05% of aluminum (sol.Al), 0.05% or less (excluding 0%) of phosphorus (P), 0.01% or less (excluding 0%) of sulfur (S), and 0.01% or less (excluding 0%) of nitrogen (N), with a remainder of Fe and other unavoidable impurities;

heating the steel slab at a temperature within a range of 1100 to 1300°C;

hot rolling the heated steel slab to manufacture a hot-rolled steel sheet;

coiling the hot-rolled steel sheet at a temperature within a range of 400 to 700°C;

cooling the hot-rolled steel sheet to room temperature after the coiling;

cold rolling the cooled hot-rolled steel sheet at a reduction rate of 55 to 80% to manufacture a cold-rolled steel sheet;

continuously annealing the cold-rolled steel sheet;

performing primary cooling to a temperature within a range of 650 to 700°C at an average cooling rate of 1 to 10 °C/s after the continuous annealing; and

performing secondary cooling to a temperature within a range of 450 to 500°C at an average cooling rate of 5

to 50°C/s, after the primary cooling,

wherein the continuous annealing is performed in an equipment equipped with a heating zone, a soaking zone, and a cooling zone, and the cold-rolled steel sheet passes through a recrystallization zone in which the cold-rolled steel sheet is maintained at a temperature within a range of 600 to 700°C for 1 to 3 minutes when the temperature of the cold-rolled steel sheet is raised to a temperature within a range of the heating zone.

9. The method for manufacturing a high-strength thick steel sheet having excellent hole expandability and ductility of claim 8, wherein the hot rolling is performed wherein temperature range of an outlet is Ar3 to 1000°C.

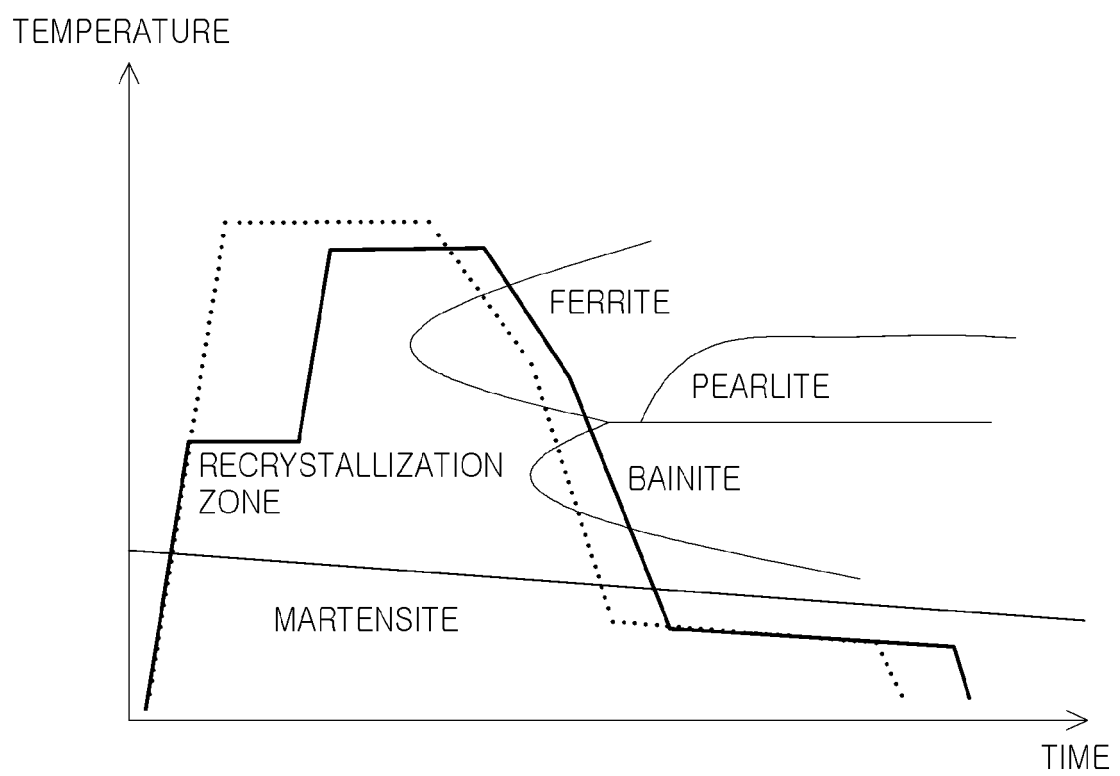
10. The method for manufacturing a high-strength thick steel sheet having excellent hole expandability and ductility of claim 8, wherein cooling after the coiling is performed at a cooling rate of 0.1°C/s or less (excluding 0°C/s) .

11. The method for manufacturing a high-strength thick steel sheet having excellent hole expandability and ductility of claim 8, wherein the heating zone and the soaking zone are controlled to a temperature within a range of 790 to 850°C.

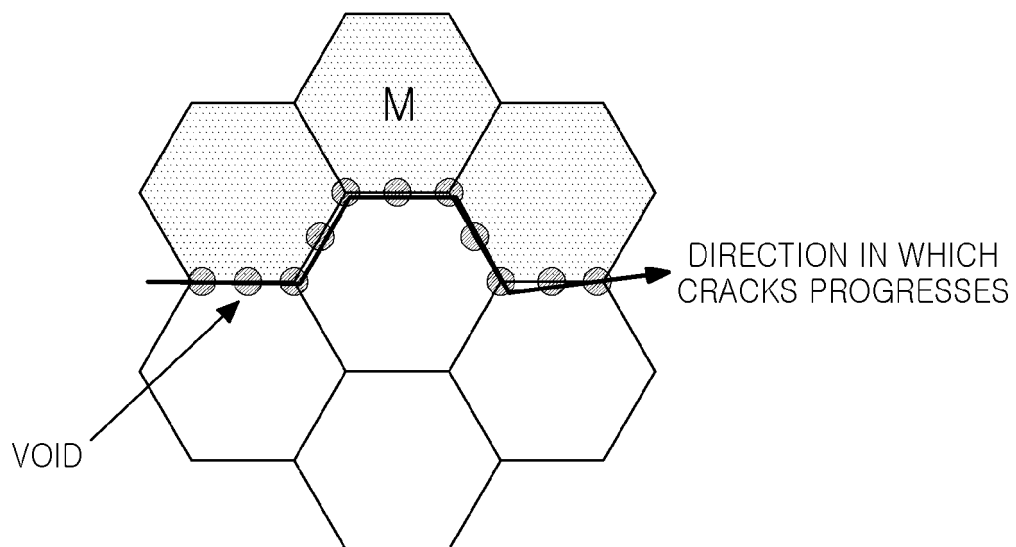
12. The method for manufacturing a high-strength thick steel sheet having excellent hole expandability and ductility of claim 8, further comprising:

performing an overaging treatment after the secondary cooling,
wherein the overaging treatment is performed for 200 to 800 seconds.

[FIG.1]

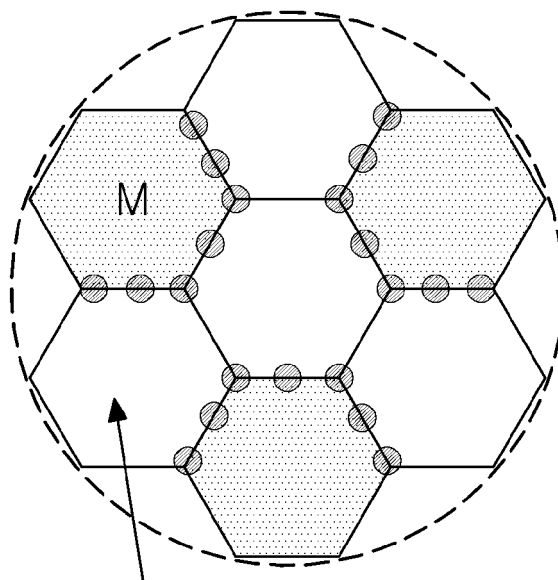


[FIG.2]



WHEN HARD PHASE HAVING DIRECTIONALITY
AND SOFT PHASE ARE SEPARATED
→ CONNECTION OF VOIDS IS EASY

(a)

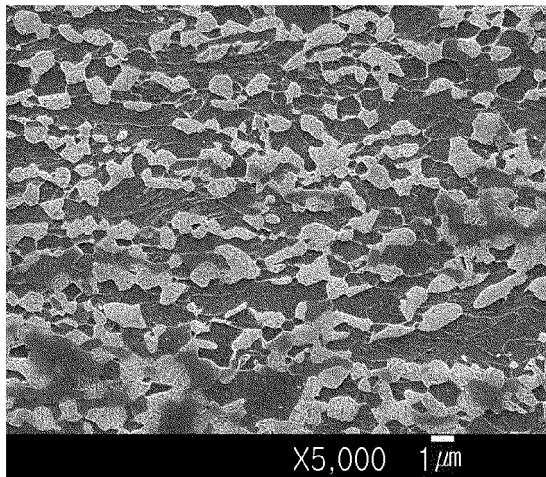


RECRYSTALLIZED α bridge EXISTS
→ CONNECTION OF VOIDS IS PREVENTED

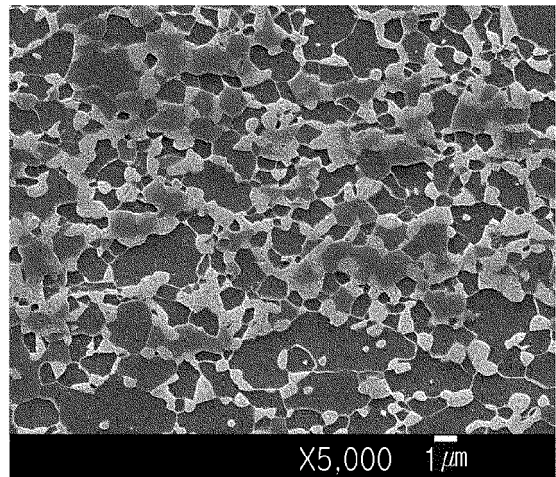
(b)

[FIG. 3]

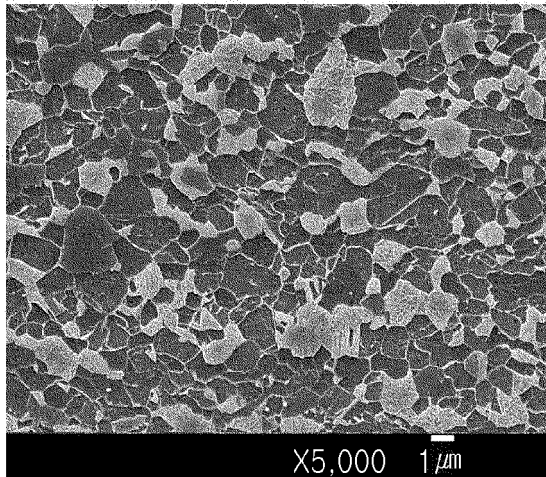
COMPARATIVE EXAMPLE 1



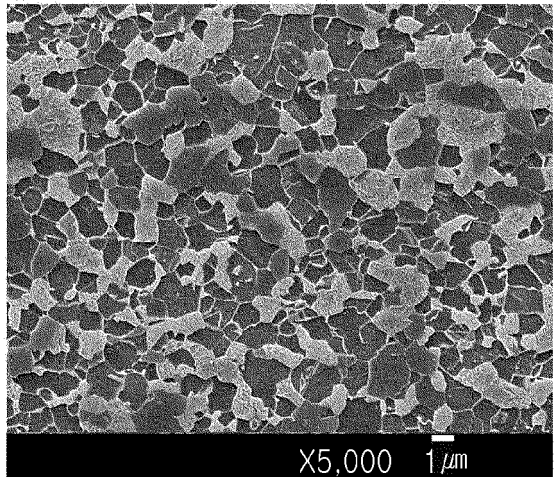
COMPARATIVE EXAMPLE 4



COMPARATIVE EXAMPLE 5

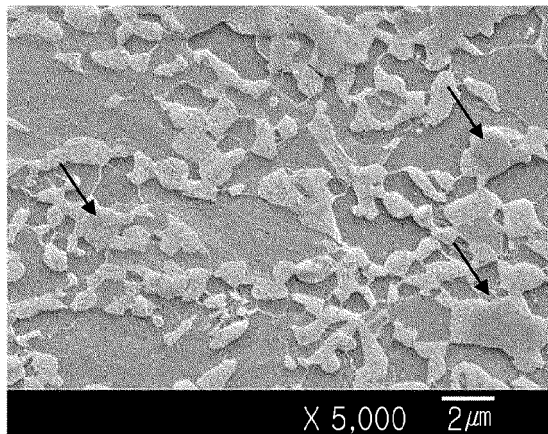


COMPARATIVE EXAMPLE 9

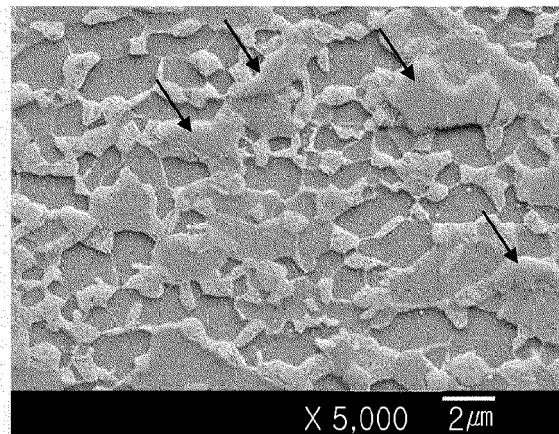


[FIG. 4]

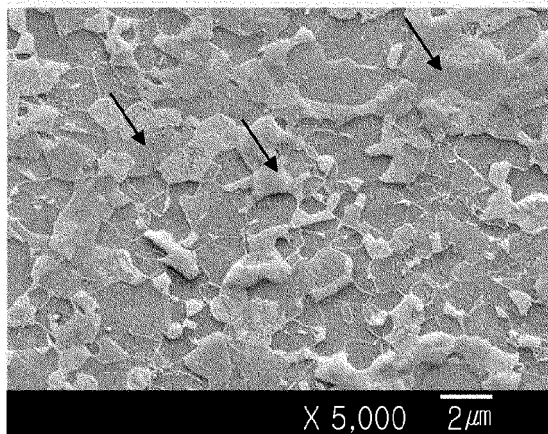
INVENTIVE EXAMPLE 1



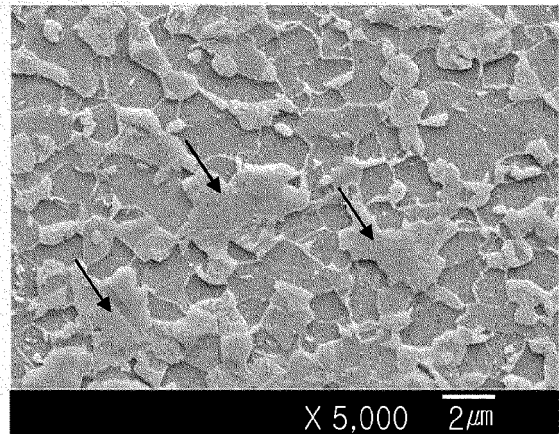
INVENTIVE EXAMPLE 3



INVENTIVE EXAMPLE 4



INVENTIVE EXAMPLE 6



INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2022/014116

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/38(2006.01)i; C22C 38/26(2006.01)i; C22C 38/28(2006.01)i; C22C 38/32(2006.01)i; C22C 38/00(2006.01)i;
C21D 8/02(2006.01)i; B21C 47/02(2006.01)i; C21D 9/46(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C 38/38(2006.01); C21D 1/18(2006.01); C21D 8/02(2006.01); C22C 38/02(2006.01); C22C 38/04(2006.01);
C23C 2/02(2006.01); C23C 2/06(2006.01)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models: IPC as above

Japanese utility models and applications for utility models: IPC as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS (KIPO internal) & keywords: 구멍 확장성(hole expandability), 연신율(elongation), 후물(thick plate), 페라이트
브리지(ferrite bridge)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	KR 10-2016-0078570 A (POSCO) 05 July 2016 (2016-07-05) See paragraphs [0073], [0079] and [0095] and claims 1, 4-5 and 9.	1-12
A	KR 10-2014-0014140 A (SALZGITTER FLACHSTAHL GMBH) 05 February 2014 (2014-02-05) See claim 1.	1-12
A	JP 5533000 B2 (SUMITOMO METAL IND., LTD.) 25 June 2014 (2014-06-25) See paragraph [0073] and figure 2.	1-12
A	KR 10-2009-0122346 A (CORUS STAAL B.V.) 27 November 2009 (2009-11-27) See paragraph [0026] and claim 1.	1-12
A	KR 10-2016-0096611 A (ARCELORMITTAL) 16 August 2016 (2016-08-16) See paragraphs [0176]-[0181] and claims 1-2.	1-12

☐ Further documents are listed in the continuation of Box C.☒ See patent family annex.

* Special categories of cited documents:

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“D” document cited by the applicant in the international application

“E” earlier application or patent but published on or after the international filing date

“L” document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

“O” document referring to an oral disclosure, use, exhibition or other means

“P” document published prior to the international filing date but later than the priority date claimed

“T” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

“X” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

“Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

“&” document member of the same patent family

Date of the actual completion of the international search

21 December 2022

Date of mailing of the international search report

22 December 2022

Name and mailing address of the ISA/KR

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EP 4 411 013 A1

INTERNATIONAL SEARCH REPORT Information on patent family members

International application No.

PCT/KR2022/014116

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
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KR 10-2014-0014140 A	05 February 2014	DE 102011117572 A1	16 August 2012
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/KR2022/014116

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
		ZA 201603640 B	29 November 2017

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REFERENCES CITED IN THE DESCRIPTION

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